Curving and looping of the internal carotid artery in relation to the pharynx: frequency, embryology and clinical implications

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(*Accepted 29 February 2000*)

ABSTRACT

Variations of the course of the internal carotid artery in the parapharyngeal space and their frequency were studied in order to determine possible risks for acute haemorrhage during pharyngeal surgery and traumatic events, as well as their possible relevance to cerebrovascular disease. The course of the internal carotid artery showed no curvature in 191 cases, but in 74 cases it had a medial, lateral or ventrocaudal curve, and 17 preparations showed kinking (12) or coiling (5) out of a total of 265 dissected carotid sheaths and 17 corrosion vascular casts. In 6 cases of kinking and 2 of coiling, the internal carotid artery was located in direct contact with the tonsillar fossa. No significant sex differences were found.Variations of the internal carotid artery leading to direct contact with the pharyngeal wall are likely to be of great clinical relevance in view of the large number of routine procedures performed. Whereas coiling is ascribed to embryological causes, curving is related to ageing and kinking is thought to be exacerbated by arteriosclerosis or fibromuscular dysplasia with advancing age and may therefore be of significance in relation to the occurrence of cerebrovascular symptoms.

Key words: Branchial arteries; tonsillectomy; haemorrhage; cerebrovascular haemodynamic changes.

INTRODUCTION

According to descriptions in most textbooks of anatomy, the cervical part of the internal carotid artery (ICA) runs a straight course to the base of the skull without branching (Henle, 1868; Sappey, 1874; Rouvière, 1924; von Lanz & Wachsmuth, 1955; Hafferl, 1957; Braus & Elze, 1960; Rauber & Kopsch, 1987; Benninghoff, 1994; Gray, 1995). As early as in 1868, Henle reported variations in the course of the ICA. Based on systematic postmortem statistics and extensive angiographic investigations, the incidence of such variations is said to lie between 10 and 40% of the population, the variations usually being normally bilateral (Cairney, 1924; Metz et al. 1961; Herrschaft, 1968, 1969; Brosig & Vollmar, 1974; Tillmann & Christofides, 1995). In an overview of large series covering more than 4000 carotid angiograms and other reports, the incidence of ICA variations has been calculated at 4–66% in adults and 16–43% in children (Desay & Toole, 1975; Leipzig & Dohrmann, 1986; Ghilardi et al. 1993; Koskas et al. 1993). Since angiographic statistics cover a preselected population, Brosig & Vollmar (1974) believed the percentage incidence to be even higher.

The ICA is at risk of injury in procedures involving the palatine tonsil (Spalteholz & Spanner, 1961; Tillmann & Schünke, 1993; Tillmann & Christofides, 1995; Tillmann, 1997). Tonsillectomy, drainage of peritonsillar abscess, soft palate impalement injuries, as well as adenoidectomy and velopharyngeoplasty, all carry the risk of ICA injury (Scillern, 1913; Fisher, 1915; Jackson, 1933; Herrmann, 1968; Riemann, 1971; Vannix et al. 1977; Kornmesser, 1978; Krmpotíc-Nemaníc, 1978; Stanton et al. 1978; Krmpotíc-Nemaníc et al. 1985; Swoboda et al. 1991; Jäckel, 1997; Schumacher et al. 1998).

The origin of the different variations has been

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controversial. Some are believed to represent congenital vascular anomalies, others to be related to arteriosclerotic pathology or fibromuscular dysplasia.

The present study was designed to evaluate variations of the ICA and their frequency in the parapharyngeal space in order to define risks for acute haemorrhage during pharyngeal surgery and traumatic events as well as their possible relevance to cerebrovascular disease. The development of the ICA is also reviewed and the genesis of the different variations is considered.

MATERIALS AND METHODS

The course of the ICA was studied in 164 head and neck preparations (79 men, 85 women; 140 left side, 142 right side; age range 52–98 y) obtained from body donors to the Department of Anatomy, Christian Albrecht University, Kiel, Germany and the Department of Anatomy, Albertus Magnus University of Cologne, Germany. During fixation of the bodies, and during investigation of the carotid arteries, the head and neck of the specimens were in the anatomical position. Fixation of the bodies was performed by perfusion with a mixture consisting of alcohol, formalin, distilled water, and glycerine via the right femoral artery. This fixation process ensures that all organs and structures, including the internal carotid artery, will have the same relationship at necropsy as in life. In 33 preparations only the right and in 31 preparations only the left side was suitable for investigation. Investigations of carotid sheaths were carried out during student dissecting courses or neck preparation courses for surgeons. Following removal of the heads with attached cervical soft tissues from the vertebral column by means of exarticulation in the atlanto-occipital position, the carotid sheaths were prepared by dorsal access to investigate the ICA, from its origin at the carotid bifurcation to its entry into the base of the skull.

In addition to these preparations, 9 corrosion vascular casts (4 men, 5 women, age range 55–77 y) of the right and left head and neck arteries from the scientific collection of the Department of Anatomy, Christian Albrecht University of Kiel, Germany were included in the investigation. The corrosion vascular casts were obtained with the head and neck in the anatomical position. In one preparation, only the left side was suitable for the investigation.

In total, 282 head and neck halves were analysed. The course of the ICA was classified as (1) straight without curvature if the deviation from the vertical was less than 15°, (2) curved, if the deviation was greater than 15° and lower than 70°, (3a) kinked, if the deviation was between 90° and 145° or, (3b) coiled, if a loop of 360° was visible. Curving was subdivided as predominantly medial, lateral or ventrodorsal. Moreover a subdivision was made into ICAs showing a kink or a coil with or without relation to the pharyngeal wall or tonsillar bed. No attempt was made to correlate the length or volume of the neck and the course of the ICA.

After analysing the topography, 7 kinks and 3 coils were resected and a radiograph was taken to look for calcification in the vessel wall as sign of degenerative change.

A total of 100 head and neck halves from 25 men and 25 women were selected at random to relate variations in course of the ICA to age; 10 heads (5 male, 5 female) came from each defined age group (Table 4).

RESULTS

The results are summarised in Tables 1–4. A straight course for the ICA (Fig. 1*a*) was observed in 191 specimens (67.7%), with a slightly more frequent occurrence in men (69.7%) than in women (66%). In 74 cases (26.2%) the ICA showed a more (Fig. 1*b*) or less (Fig. 1*d*) curved course to the base of the skull. The convexity of the curve was medial in 30 cases (10.6%) and lateral in 38 cases (13.5%). Six specimens (2.1%) revealed an ICA with a ventrodorsal curve (Fig. 1*b*). Curvature was somewhat more frequent in women (27.3%) than in men (25%).

Seventeen specimens (6%) showed pronounced kinking or coiling (Fig. 2). In 9 cases (3.2%) this variation was situated in the peripharyngeal space but without a close relation to the pharyngeal wall in the region of transition between the mesopharynx and hypopharynx (Fig. 2*a*). In 8 specimens (2.8%), the variation was situated directly behind the tonsillar bed of the pharynx (Fig. 2*b–d*). Kinking (Fig. 2*b*, *c*) was detected in 12 specimens (4.3%) and coiling (Fig. 2*d*) in 5 specimens (1.8%). Similar results were found in relation to sex, with coiling or kinking being slightly more frequent in females (6.7%) than in males (5.3%). No significant differences were observed in comparisons of ICA variations between the left and right sides.

X-ray analysis showed in all 7 kinks investigated marked calcifications of the vessel wall in front of the kink (Fig. 5*a*), whereas coiling in only one of the 3 cases was associated with calcifications of the vessel wall. In this case only a few small calcified areas were visible (Fig. 5*b*).

Table 1. *Course of the ICA related to all specimens investigated*

	Course of the ICA	Number of specimens N = 282	Percentage 100.00
1	Straight	191	67.73
2	Curved	74	26.24
	Medially	30	10.64
	Laterally	38	13.48
	Ventrodorsally	6	2.13
3	Kinking or coiling	17	6.03
	Without relation to the pharyngeal wall	9	3.19
	With relation to the pharyngeal wall	8	2.84
3a	Kinking only	12	4.26
	Without relation to the pharyngeal wall	6	2.13
	With relation to the pharyngeal wall	6	2.13
3b	Coiling only	5	1.77
	Without relation to the pharyngeal wall	3	1.06
	With relation to the pharyngeal wall	2	0.71

Table 2. *Course of the ICA related to women*

	Course of the ICA	Number of specimens N = 150	Percentage 100.00
1	Straight	99	66.00
2	Curved	41	27.33
	Medially	16	10.67
	Laterally	22	14.67
	Ventrodorsally	3	2.00
3	Kinking or coiling	10	6.67
	Without relation to the pharyngeal wall	5	3.33
	With relation to the pharyngeal wall	5	3.33
3a	Kinking only	8	5.33
	Without relation to the pharyngeal wall	4	2.67
	With relation to the pharyngeal wall	4	2.67
3b	Coiling only	2	1.33
	Without relation to the pharyngeal wall	1	0.67
	With relation to the pharyngeal wall	1	0.67

Table 3. *Course of the ICA related to men*

	Course of the ICA	Number of specimens N = 132	Percentage 100.00
1	Straight	92	69.70
2	Curved	33	25.00
	Medially	14	10.61
	Laterally	16	12.12
	Ventrodorsally	3	2.27
3	Kinking or coiling	7	5.30
	Without relation to the pharyngeal wall	4	3.03
	With relation to the pharyngeal wall	3	2.27
3a	Kinking only	4	3.03
	Without relation to the pharyngeal wall	2	1.51
	With relation to the pharyngeal wall	2	1.51
3b	Coiling only	3	2.27
	Without relation to the pharyngeal wall	2	1.51
	With relation to the pharyngeal wall	1	0.76

Analysis of the 109 head and neck preparations in which the ICAs were inspected on both sides (including corrosion vascular casts) revealed a nearly identical course of the blood vessels on the right and left sides. Coiling of the ICA was found in male specimens only, on the right side, with the left side

Table 4. *Variations in course of ICA related to age*

Age (y)	Straight		Curved		Kinking		Coiling	
	female	male	female	male	female	male	female	male
50–60	9	8	1	—	—	—	—	2
61–70	9	9	1	1	—	—	—	—
71–80	6	9	3	1	1	—	—	—
81–90	5	4	5	4	—	2	—	—
> 90	6	4	4	5	—	1	—	—

N = 100 (50 female, 50 male), N = 20 (10 female, 10 male) in each age group.

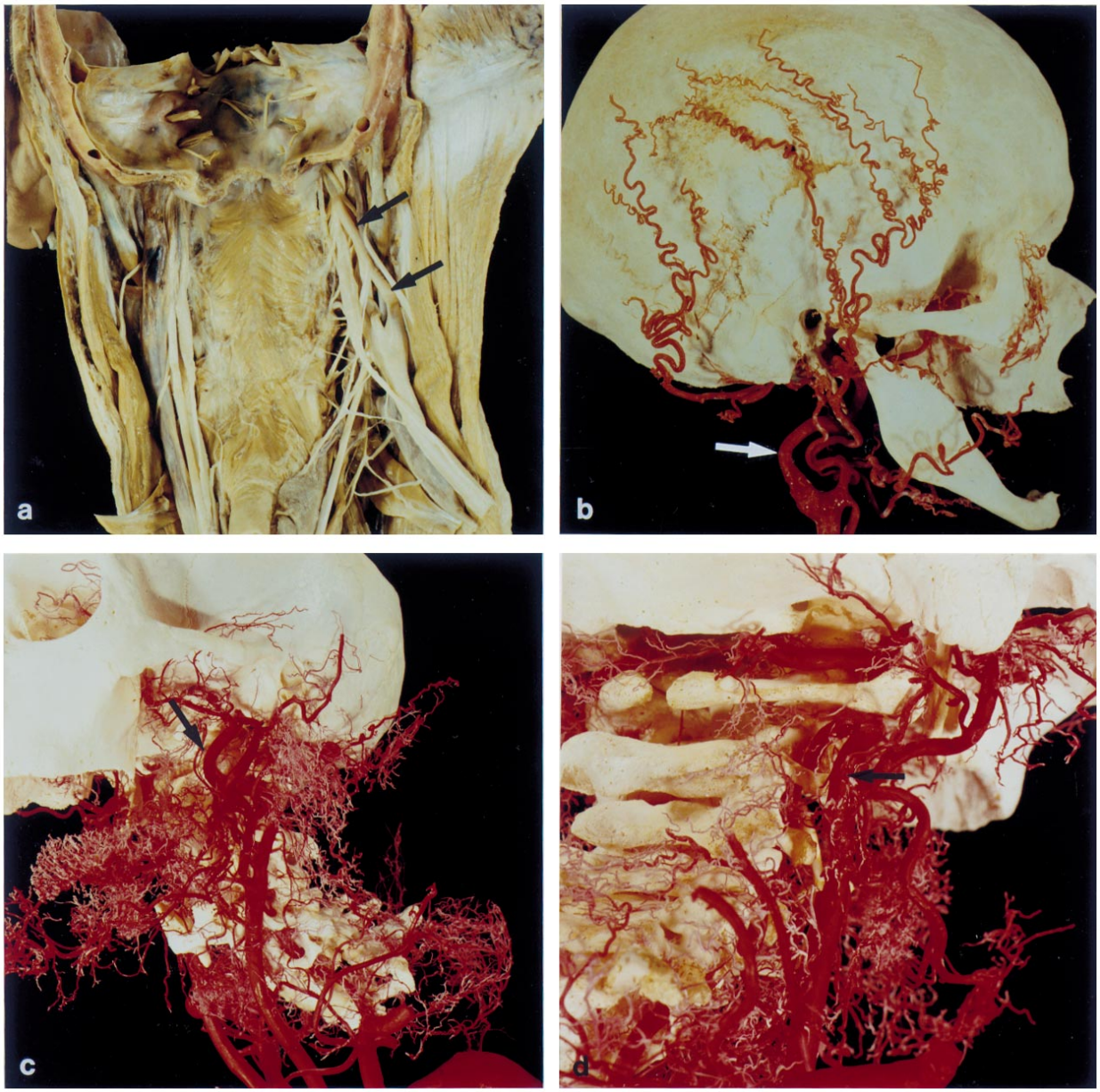

Fig. 1. Straight course and curvature of the internal carotid artery. (*a*) Dorsal view of a prepared head and neck specimen (male, 66 y) showing a straight course of the internal carotid artery (arrows). (*b*) Corrosion vascular cast of the head and neck area with intact skeleton of the skull (female, 82 y) revealing an internal carotid artery with ventrodorsal curvature (arrow). (*c*) Corrosion vascular cast of the head and neck area with intact skeleton (male, 79 y). The internal carotid artery displays, in the area of the axis and atlas, a ventral curve around the transverse process of the atlas (arrow). (*d*) Dorsal view on a corrosion vascular cast (male, 79 y) showing a less curved course of the internal carotid artery (arrow).

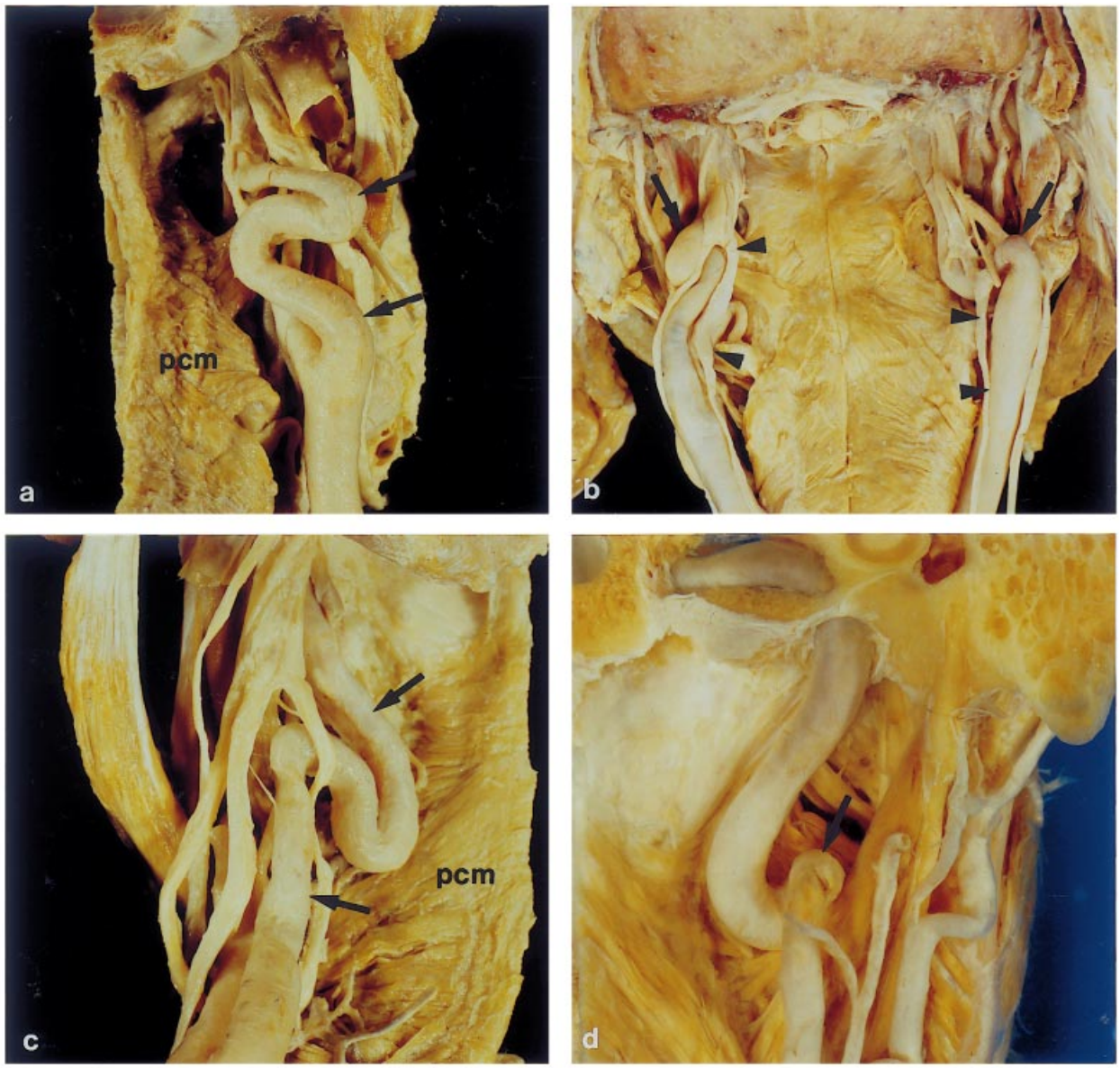

Fig. 2. Dorsal views of prepared head and neck specimens showing kinking and coiling of the internal carotid artery. (*a*) Right side of a head and neck preparation. The internal carotid artery (arrows) shows kinking (female, 63 y) without pharyngeal wall contact. pcm, pharyngeal constrictor muscle. (*b*) Kinking of the internal carotid artery (arrows) on both sides (male, 73 y). The kinked arteries are in close contact to the pharyngeal wall. Also a close relationship to the vagus nerve is evident (arrowheads). (*c*) Left side of a head and neck preparation. The internal carotid artery (arrows) shows kinking (male, 76 y) and close contact with the pharyngeal wall. pcm, pharyngeal constrictor muscle. (*d*) Looping of the internal carotid artery (arrow) with close pharyngeal wall contact in the area of the tonsillar bed (male, 80 y).

showing strong medial curvature. In female specimens, coiling was visible on both sides, on the left with a close relation to the pharyngeal wall and on the right without such close proximity.

One corrosion vascular cast of a male head and neck showed an ICA which, in the region of the head-neck transition, assumed the form of a ventrally straightened sling curving around the transverse process of the atlas (Fig. 1*c*).

Variations in ICA course related to age in 100 head and neck halves revealed that curvature and kinking are related to the older age group, whereas coiling alone was seen in the 50–60-y-old group.

DISCUSSION

The present study was designed to determine the frequency of variations of the ICA related to the pharyngeal wall. The large number of routine procedures performed in patients in the area of the tonsillar fossa and the occurrence of atherosclerotic lesions in this region make these variations clinically relevant.

Initial clinical descriptions of lethal complications based on injuries of aberrant ICA segments at the lateral and posterior pharyngeal wall subsequent to tonsillectomy and adenoidectomy came from

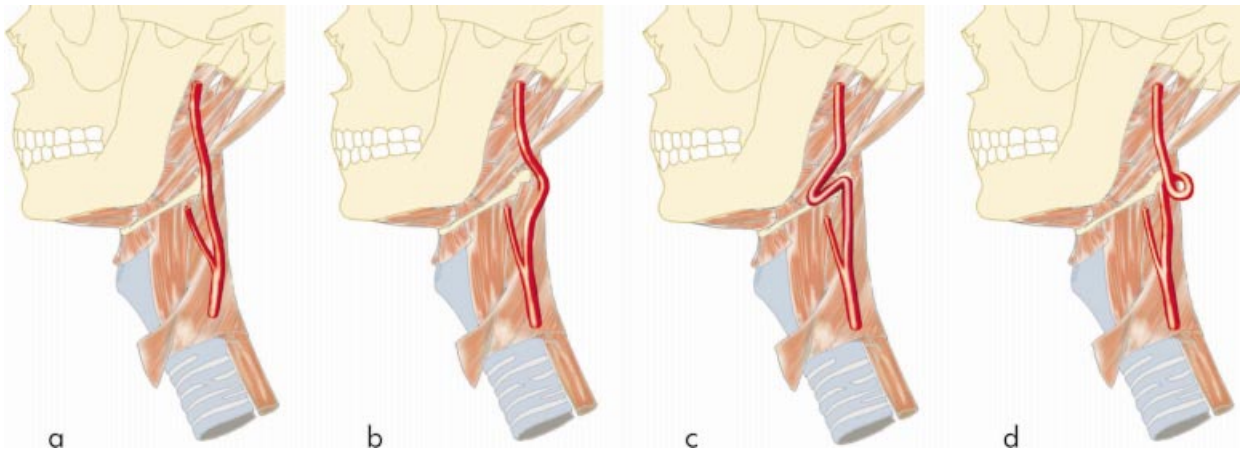

Fig. 3. Schematic drawings of form and course variations of the cervical internal carotid artery. (*a*) straight course, (*b*) curved course, (*c*) kinking, (*d*) coiling.

otorhinolaryngologists (Scillern, 1913; Fisher, 1915; Schaeffer, 1921; Kelly, 1925; Jackson, 1933). Injury to the ICA during tonsillectomy may result in a life-threatening acute haemorrhage because of tortuosity of this vessel not apparent preoperatively and in close relation to the tonsillar bed (Gardner, 1968; Herrmann, 1968; Herrschaft, 1969; Osguthorpe et al. 1981). In this context, the distance between the tonsillar fossa and the ICA is of considerable relevance, particularly in children (Deutsch et al. 1995). However, tonsillectomy and adenoidectomy are both performed almost exclusively in children and youths, and extrapolation to these from the data of the present study in which the 'youngest' subject was 52 is questionable at the least. Nevertheless, Jäckel (1997) demonstrated impressively that aberrant segments of the ICA are of clinical significance, even in the older age group represented in our study. In this group, the patients suffered from recurring difficulties with swallowing and speech or increasing sensations of a foreign body in the area of the pharynx. Injury of the ICA in this age group can result from diagnostic puncture or biopsy, since retropharyngeal masses in most instances arouse suspicion of malignant disease. Based on acute bleeding from injuries of the ICA and of the often irremediable neurological deficits resulting from ligation of this vessel, the term dangerous loop of the ICA was coined (Tillmann & Schünke, 1993; Tillmann & Cristofides, 1995).

In addition to looping, other variations of the ICA have been described with a somewhat confusing nomenclature. Initially, Weibel & Fields (1965) introduced a classification which is still valid today (Fig. 3). They distinguished between (1) a straight course of the ICA, (2) an S or C-shaped elongation with medial and/or lateral displacement of the elongated segment, (3) a kinking of one or more segments, and (4) coiling of the artery which may also appear as a double loop. Our results show a further type of variation belonging to the group with S or C-shaped elongation. This shows neither a medially nor a laterally displaced segment but ventral and dorsal folding and is therefore classified as the ventrodorsal type (Tables 1–3).

S or C-shaped elongations and tortuosities, kinkings and loops of the ICA are thought to be congenital anomalies (Cairney, 1924). Their genesis can be explained in terms of the embryological development of the branchial arch arteries (Fig. 4). The ICA develops on both sides out of the third aortic arch (third branchial arch artery) and the cranial part of the dorsal aorta. According to Kelly (1925) a loop is formed at the junction between the 2 blood vessels, reaching its maximal extension in the fifth and sixth embryonic weeks. Normally, the descent of the large blood vessels and the heart into the mediastinal space during continuous development leads to elongation and straightening of the artery. Failure of this process, incomplete development, or accelerated linear growth of the artery can result in a persistence of the loop. A looped ICA can thus be considered as representing a rudimentary stage of development. The frequency of such embryological developmental disturbances has been said to vary between 5 and 10% in infancy (Cairney, 1924; Herrschaft, 1968; Ricciardelli et al. 1989). However, nowhere in the literature is there any proof that the variations of the ICA are in fact congenital. On the other hand, curvature and coiling are found in many other vessels, such as the vertebral artery, where no embryological explanation for such coiling can be provided. Among others, Ravensbergen et al. (1993) studied the basilar artery in neonates and adults and concluded that the frequently encountered curvature of the basilar artery is related to ageing. Wensing et al. (1995), studying the femoral artery in

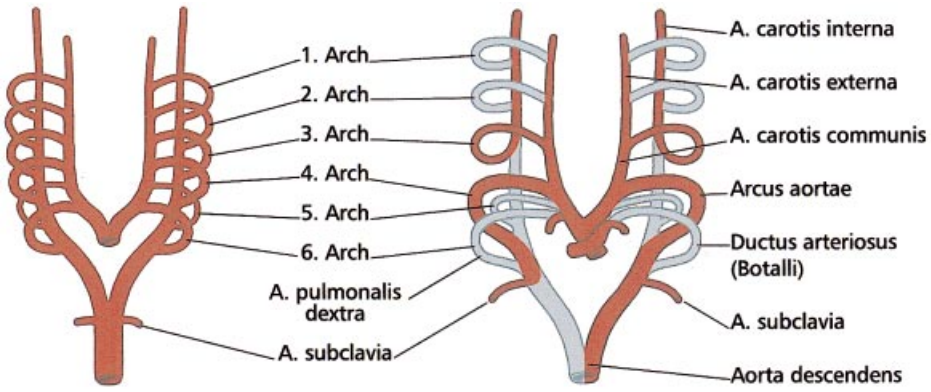

Fig. 4. Schematic drawing of the embryonic development of the branchial arch arteries. Blood vessel segments which obliterate during development are dotted grey (modified from Braus-Elze, 1960).

various age groups using MR, found increased coiling and kinking with age. Chilvers et al. (1974) had described elongation and Learoyd & Taylor (1966) attributed the phenomenon to loss of elasticity. In many other species, the course of the ICA is regularly curved. For example, the ICA of the seal has been measured to be 40 times longer than the actual distance bridged (Chauveau, 1898).

As a rule, ICA variations are symptomless and remain undiscovered (Demme, 1901; Bergvist, 1946; Dohrmann, 1986; Ord & Ward-Booth, 1986). With advancing age, the variations may lead to complaints in the context of degenerative alterations of the blood vessels (Weibel & Fields, 1965). A possible link between lesions of the carotid artery and cerebrovascular disease was first raised during observation on clinical symptoms such as hemiplegia (Quattlebaum et al. 1959) and cerebrovascular insufficiency (Metz et al. 1961; Derrick & Smith, 1962) associated with concurrent ICA variations. Degenerative alterations common in subjects aged over 50 y may increase the dimensions of the kink or coil and may include local symptoms in the neck including discomfort and local bruits (Schenk et al. 1996). Since the anomaly is usually first discovered within a context of clinical symptoms, its incidence shows an apparent statistical preference for higher age groups (Weibel & Fields, 1965) and therefore is considered to be based on an age-related loss of elasticity in the vessel wall (Herrschaft, 1968). Schenk et al. (1996) believed that only kinking of the ICA is related to old age, whereas curvature and coiling are congenital. Our results indicate that both kinking and curvature are features that show an increased prevalence in old age (Table 4). Kinking is thought to be associated with arteriosclerosis, stenosis, vasculitis, atrophic dilatation, loss of elasticity, or dissection in the context of fibromuscular dysplasia (Schenk et al. 1996). Nevertheless, in view of the altered fluid dynamics in the presence of vascular curves, kinks and coils it is not surprising that kinking is more frequently associated with cerebrovascular disease than curving and coiling of the ICA. In kinks, blood flow is impeded by vortex formation, whereas with curves and coils haemorrhage from inadvertent injury is more likely. The altered fluid dynamics produced by kinks may lead more frequently to degenerative changes in the vessel wall (Fig. 5).

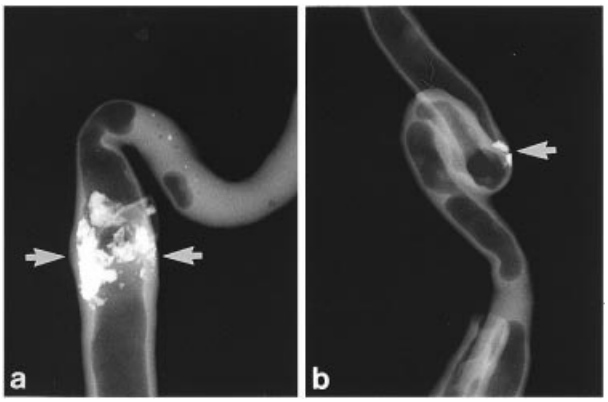

Fig. 5. (*a*) Radiograph of an ICA where kinking was detected. Marked calcifications (arrows) are visible in front of the kink (male, 68 y). (*b*) Radiograph of an ICA where coiling was detected. Two small points of calcification (arrow) are visible in the final part of the loop (male, 65 y).

With the exception of a few hints in the anatomical literature on the variations of the ICA mentioned at the outset, detailed descriptions of the variations have arisen from clinical observations. According to an evaluation of 5542 angiograms made by Herrschaft (1969), which was based on his own results as well as descriptions in the literature, the course of the ICA is straight at the neck in 82.7% and arched in a C or S shape in 12.2%. 5.1% of the angiograms revealed an 'extremely sigmoid, siphon, or circular ansa'. According to Lazorthes et al. (1961) coiling or kinking of

the ICA and a close relationship of the variations to the palatine tonsil is present in 20% of cases. This result reveals a significant difference from the observed frequency of variations as observed in anatomical preparations. In the present observations, material coiling or kinking was detected with a frequency of 6%. This result is compatible with the findings of Herrschaft (1969). Although Herrschaft observed curvature of the ICA with a frequency of 12.2%, the present study found curvature in 26.2%. Nevertheless, caution is advised when extrapolating from a subpopulation in the dissecting room to the subpopulation undergoing angiography, since selection factors vary for these different subpopulations.

In conclusion, the described ICA variations occur with a frequency of 65–70% for a straight course, 25–28% for a curved course and 5–7% for kinking or coiling, kinking being seen more frequently than coiling. Similar results are found in both sexes. Variations of the course of the ICA at the posterior wall of the pharynx are of clinical relevance in the context of various otorhinolaryngological operations and other routine procedures and therefore should be excluded before to surgery by imaging methods. This is of particular relevance if coiling of the ICA is assumed to be congenital. Based on our results, variations in the course of the ICA appear to depend on age. In this context, kinking is frequently associated with degenerative changes of the vessel wall in advanced age and may predispose to atherosclerotic stenosis. It remains unclear whether coiling of the ICA is present congenitally or acquired during life. In the future, the noninvasive techniques now available for imaging of the cervical arteries at any age, such as magnetic resonance angiography, may supply new insights.

ACKNOWLEDGEMENTS

The authors thank Rolf Klaws for the preparation of the corrosion vascular casts and Clemens Franke for the line drawings.

REFERENCES

BENNINGHOFF A (1994) Blutgefäße des Zentralnervensystems. In *Anatomie: Makroskopische Anatomie, Embryologie und Histologie des Menschen* (ed. Drenckhahn D, Zenker W) vol. 1, 15th edn, pp. 361–380. München: Urban & Schwarzenberg.

BERGVIST B (1946) Anomalies in the course of arteria carotis interna in the upper region of the pharynx. *Acta Oto-Laryngologica* **66**, 246–255.

BRAUS H, ELZE C (1960) *Anatomie des Menschen*. Vol. III: *Periphere Leitungsbahnen II, Zentrales Nervensystem, Sinnesorgane*, 2nd edn. Berlin: Springer.

BROSIG HJ, VOLLMAR J (1974) Chirurgische Korrektur der Knickstenosen der A. carotis interna. *Münchener Medizinische Wochenschrift* **116**, 969–982.

CAIRNEY J (1924) Tortuosity of the cervical segment of the internal carotid artery. *Journal of Anatomy* **59**, 87–96.

CHAUVEAU A (1898) *Comparative Anatomy of the Domesticated Animals*, 2nd edn, p. 680. New York: Appleton.

CHILVERS AS, THOMAS ML, BROWSE NL (1974) The progression of arteriosclerosis. A radiological study. *Circulation* **50**, 402–408.

DEMME K (1901) Über Gefäßanomalien im Pharynx. *Wiener Medizinische Wochenschrift* **51**, 22–45.

DERRICK JR, SMITH T (1962) Carotid kinking as a cause of cerebral insufficiency. *Circulation* **25**, 849–853.

DESAY B, TOOLE JF (1975) Kinks, coils, and carotids: a review. *Stroke* **6**, 649–653.

DEUTSCH MD, KRISS VM, WILLGING P (1995) Distance between the tonsillar fossa and internal carotid artery in children. *Archives of Otolaryngology Head and Neck Surgery* **121**, 1410–1412.

DOHRMANN GJ (1986) The tortuous or kinking carotid artery, pathogenesis and clinical considerations, a historical review. *Surgical Neurology* **25**, 478–486.

FISHER AGT (1915) Sigmoid tortuosity of the internal carotid artery and its relation to tonsil and pharynx. *Lancet* **2**, 128–130.

GARDNER JF (1968) Sutures and disasters in tonsillectomy. *Archives of Otolaryngology* **88**, 551–555.

GHILARDI G, LONGHI F, DE MONTI M, BORTOLANI E (1993) Kinking carotideo ed ipertensione arteriosa. Risultati preliminari del programma OPI. *Minerva Cardioangiologica* **41**, 287–291.

GRAY H (1995) Cardiovascular: internal carotid artery. In *Gray's Anatomy* (ed. Williams PL, Bannister LH, Berry MM, Collins P, Dyson M, Dussek JE et al.), 38th edn, pp. 1523–1529. Edinburgh: Churchill Livingstone.

HAFFERL A (1957) *Lehrbuch der topographischen Anatomie*, 2nd edn. Berlin: Springer.

HENLE J (1868) *Handbuch der Gefäßlehre des Menschen*, vol. III. Braunschweig: Viehweg und Sohn.

HERRMANN A (1968) *Gefahren bei Operationen am Hals, Ohr und Gesicht und die Korrektur fehlerhafter Eingriffe*. Berlin: Springer.

HERRSCHAFT H (1968) Zerebrale Durchblutungsstörungen bei extremer Schlingenbildung der Arteria carotis interna. *Münchner Medizinische Wochenschrift* **110**, 2694–2702.

HERRSCHAFT H (1969) Abnorme Schlingenbildungen der A. carotis interna und ihre klinische Bedeutung bei Operationen im Halsbereich. *Zeitschrift für Laryngologie und Rhinologie* **2**, 85–98.

JÄCKEL M (1997) Verlaufsvarianten der A. carotis interna als Differentialdiagnose parapharyngealer Raumforderungen. *Hals-Nasen-Ohrenheilkunde, Kopf- und Hals-Chirurgie* **45**, 1018–1021.

JACKSON JL (1933) Tortuosity of the internal carotid artery and its relation to tonsillectomy. *Canadian Medical Association Journal* **29**, 475–479.

KELLY AB (1925) Tortuosity of the internal carotid artery in relation to the pharynx. *Journal of Laryngology and Otology* **40**, 15–23.

KORNMESSER HJ (1978) Blutungen und Blutstillung im Bereich des Gesichtsschädels, des Halses und des Mittelohres. *Archives of Otorhinolaryngology* **219**, 209–283.

KOSKAS F, BAHNINI A, WALDEN R, KIEFFER E (1993) Stenotic coiling and kinking of the internal carotid artery. *Annals of Vascular Surgery* **7**, 530–540.

KRMPOTÍC-NEMANÍC J (1978) Anatomie, Variationen und Mißbildungen der Gefäße im Kopf- und Halsbereich. *Archives of Otorhinolaryngology* **218**, 1–77.

KRMPOTÍC-NEMANÍC J, DRAF W, HELMS J (1985) *Chirurgische Anatomie des Kopf-Hals-Bereiches*. Berlin: Springer.

LAZORTHES G, BASTIDE G, GOMÈS FA (1961) Les variations du trajet de la carotide interne d'après une étude artériographique. *Archives d'Anatomie Pathologique* **9**, 130–134.

LEAROYD BM, TAYLOR MG (1966) Alterations with age in the viscoelastic properties of human arterial walls. *Circulation Research* **18**, 278–292.

LEIPZIG TJ, DOHRMANN GJ (1986) The tortuous or kinked carotid artery: pathogenesis and clinical considerations. A historical review. *Surgical Neurology* **25**, 478–486.

METZ H, MURRAY-LESLIE RM, BANNISTER RG, BULL JWD, MARSHALL J (1961) Kinking of the internal carotid artery in relation to cerebrovascular disease. *Lancet* **1**, 424–426.

ORD R, WARD-BOOTH R (1986) Anomalies of the common carotid artery, a rare complication of radical neck dissection. *British Journal of Oral and Maxillofacial Surgery* **24**, 405–409.

OSGUTHORPE JD, ADKINS WY, PUTNEY FJ, HUNGERFORD GD (1981) Internal carotid artery as source of tonsillectomy and adenoidectomy hemorrhage. *Otolaryngology Head and Neck Surgery* **89**, 758–762.

QUATTLEBAUM JK, UPSON ET, NEVILLE RL (1959) Stroke associated with elongation and kinking of the internal carotid artery: report of three cases treated by segmental resection of the carotid artery. *Annals of Surgery* **150**, 824–832.

RAUBER A, KOPSCH F (1987) Kreislaufsystem: Bauplan des Kreislaufsystems. In *Anatomie des Menschen*. (ed. Leonhardt H, Tillmann B, Töndury G, Zilles K) vol. 2, 20th edn, pp. 22–29. Stuttgart: Thieme.

RAVENSBERGEN J, HILLEN B, HOOGSTRATEN HW, KRIJGER JKB (1993) Do haemodynamic forces bend the basilar arteries? *Journal of Anatomy* **182**, 144.

RICCIARDELLI E, HILLELL AD, SCHWARTZ AN (1989) Aberrant carotid artery. *Archives of Otolaryngology* **115**, 519–522.

RIEMANN D (1971) Über Verlaufsanomalien der inneren Kopfarterien im extrakraniellen Teil (aberrierende Arteria carotis interna) und ihre forensische Bedeutung bei Operationen. *HNO* **19**, 117–121.

ROUVIÉRE H (1924) *Anatomie Humaine Descriptive et Topographique*, tome I, Paris: Masson.

SAPPEY PHC (1874) *Traité d'Anatomie Descriptive*, tome II, Paris: Delahaye.

SCHAEFFER JP (1921) Aberrant vessels in surgery of the palatine and pharyngeal tonsils. *Journal of the American Medical Association* **77**, 14–19.

SCHENK P, TEMMEL A, TRATTNIG S, KAINBERGER F (1996) Aktuelle Aspekte in der Diagnostik und Therapie des Karotiskinking. *Hals-Nasen-Ohrenheilkunde*, *Kopf- und Hals-Chirurgie* **44**, 178–185.

SCHUMACHER WA, SCHAFIG A, KEHRL W, PAU HW (1998) Verlaufsvarianten der Arteria carotis interna: Mögliche Risiken bei sogenannten Standardoperationen im Pharynxbereich. *Laryngologie*, *Rhinologie*, *Otologie* **77**, 517–520.

SCILLERN PG (1913) Anomalous internal carotid artery and its clinical significance in operations on tonsils. *Journal of the American Medical Association* **60**, 172–173.

SPALTEHOLZ W, SPANNER R (1961) *Handatlas der Anatomie des Menschen*. Vol II: *Gefäß-System*, *Eingeweide*, *Nervensystem*, *Sinnesorgane*, 16th edn. Amsterdam: Scheltema & Holkema.

STANTON PE, McCLUSKY DA, LAMIS PA (1978) Hemodynamic assessment and surgical correlation of kinking of the internal carotid artery. *Surgery* **84**, 793–802.

SWOBODA H, CZECH T, SCHINDLER E (1991) Aberrierende Strombahn einer Arteria carotis interna durch das Mittelohr. *Hals-Nasen-Ohrenheilkunde*, *Kopf- und Hals-Chirurgie* **39**, 315–320.

TILLMANN B (1997) *Farbatlas der Anatomie. Zahnmedizin-Humanmedizin*. Stuttgart: Thieme.

TILLMANN B, SCHÜNKE M (1993) *Taschenatlas zum Präparierkurs. Eine klinische orientierte Anleitung*. Stuttgart: Thieme.

TILLMANN B, CHRISTOFIDES C (1995) Die 'gefährliche Schleife' der Arteria carotis interna. *HNO* **43**, 601–604.

VANNIX RS, JOERGENSON EJ, CARTER R (1977) Kinking of the internal carotid artery. Clinical significance and surgical management. *American Journal of Surgery* **134**, 82–89.

VON LANZ T, WACHSMUTH W (1955) *Praktische Anatomie. Kopf*, vol I/I, Berlin: Springer.

WEIBEL J, FIELDS WS (1965) Tortuosity, coiling, and kinking of the internal carotid artery. *Neurology* **15**, I 7–18, II 462–468.

WENSING PJW, SCHOLTEN FG, BUIJS PC, HARTKAMP MJ, MALI WPTM, HILLEN B (1995) Arterial tortuosity in the femoropopliteal region during leg flexion: an MRA study. *Journal of Anatomy* **186**, 133–139.